

AN *INTEGRAL* OBSERVATION OF THE BLACK HOLE TRANSIENT 4U 1630–47 AND THE NORMA REGION OF THE GALAXY

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ABSTRACT

We report on results from a 2003 February *INTEGRAL* observation of the black hole candidate (BHC) 4U 1630–47 and the high energy sources in the Norma Region of the Galaxy and on *RXTE* and radio observations of 4U 1630–47. To date, there have been 38 new or previously poorly studied sources found by *INTEGRAL* (the “IGR” sources), and 15 of the IGR sources are in the field of view of our observation. We detect 12 of the 15 sources, and we speculate that a subset of the IGR sources may be part of a new population of persistent, hard, intermediate luminosity X-ray sources. During our observations, 4U 1630–47 was in an intermediate state with strong soft and hard components, a power-law index of $\Gamma = 2.11$ – 2.18 , a 4% rms level of timing noise (0.1–10 Hz), and the source was not detected in the radio band. We discuss the evolution of the energy spectrum during the 293 ks *INTEGRAL* observation, and we report on rapid, high amplitude flaring behavior that has been seen for much of the 2002–2004 outburst.

Key words: accretion, accretion disks — black hole physics: general — stars: individual (4U 1630–47) — stars: black holes — X-rays: stars.

1. INTRODUCTION

The X-ray flux observed from transient X-ray binaries changes by several orders of magnitude between quiescence and outburst, providing an opportunity to learn about black hole candidates (BHCs), accretion onto compact objects, and the processes responsible for high energy emission. Although these objects are known to emit hard X-rays and gamma-rays, the origin of this emission is not well-understood. The high energy emission

provides a probe of the regions of space close to the compact object, allowing us to study strong gravity and jet formation processes. 4U 1630–47 is among the most active of the BHC X-ray transients and has produced strong hard X-ray emission during its 17 detected outbursts (Tomsick & Kaaret, 2000; Oosterbroek et al., 1998; Kuulkers et al., 1997; Parmar et al., 1997) as well as highly polarized radio emission (Hjellming et al., 1999), indicating the presence of jets. The current outburst from 4U 1630–47, which began in 2002 September, is one of the brightest and longest recorded outbursts from this system, and we had the opportunity to observe 4U 1630–47 with *INTEGRAL* in 2003 February.

Due to the large *INTEGRAL* field of view, we also detect many other hard X-ray sources in the vicinity of 4U 1630–47. Several of the sources were unknown or poorly studied prior to *INTEGRAL* and have “IGR” designations. Although we are just beginning to understand the nature of the IGR sources, many of these appear to be highly absorbed ($N_H = 10^{23-24}$ cm^{−2}), and some of them are bright IR sources (e.g., Matt & Guainazzi, 2003; Walter et al., 2004; Patel et al., 2004, and papers by Foschini, Walter, and others in these proceedings). The concentration of IGR sources near 4U 1630–47 is almost certainly due to the location of the source in the Galactic plane ($l = 336.91^\circ$, $b = +0.25^\circ$). This is in the Norma region of the Galaxy, and the line of sight to 4U 1630–47 is tangent to the Norma-Scutum Galactic arm. Below, we present our results on: The hard X-ray sources detected by *INTEGRAL* in the Norma region; and X-ray and radio observations of 4U 1630–47.

2. OBSERVATIONS

We obtained the following observations of 4U 1630–47 for this project:

- *INTEGRAL*: Our observations with *INTEGRAL*

lasted from UT 2003 February 1, 5.7 h to UT 2003 February 5, 7.9 h, with a total of 293 ks on source.

- *RXTE*: 4U 1630–47 has been monitored throughout the current outburst with the *Rossi X-ray Timing Explorer (RXTE)*. Five *RXTE* observations occurred during or within a day of the *INTEGRAL* observation, yielding 43 ks with the Proportional Counter Array (PCA) and 28 ks with the High Energy X-ray Timing Experiment (HEXTE).

- *Radio*: We observed 4U 1630–47 on 2003 January 26 and 27 at 4.8 and 8.6 GHz. The target was not detected with an rms level of 0.1 mJy.

3. RESULTS

3.1. The Norma Region Sources

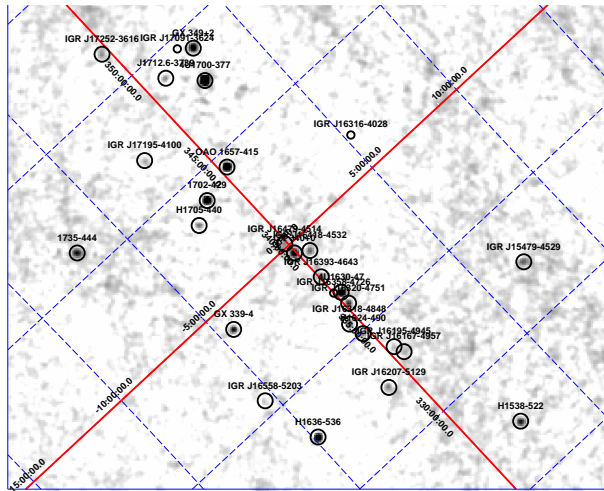


Figure 1. 20–40 keV ISGRI significance image from our 2003 February 293 ks *INTEGRAL* observation. Detected sources that we identified are marked with larger circles, and IGR sources reported in other observations that are not detected in our observation are marked with smaller circles.

Figure 1 shows the 20–40 keV IBIS image from our 2003 February observation of 4U 1630–47. The field of view covered by IBIS includes 15 of the 38 IGR sources that have been found to date (as of 2004 March). Thus, this relatively long single exposure provides a useful study of a significant subset of the IGR sources. Table 1 lists the 15 IGR sources along with detection significances ($\text{SNR} = \text{signal-to-noise ratio}$) and ISGRI count rates or upper limits. We detect 12 out of 15 of the IGR sources, and we note that we used these data to report the discovery of three of the sources (Tomsick et al., 2003, 2004). In addition, the table gives information about identifications or possible identifications with other high energy sources or with sources at other wavelengths. In many cases, this information is in the discovery references (also given in the table), and we also searched the SIMBAD database to look for likely or possible identifications. The density of sources within about

4° of 4U 1630–47 is especially high, and Figure 2 shows a close-up of this region.

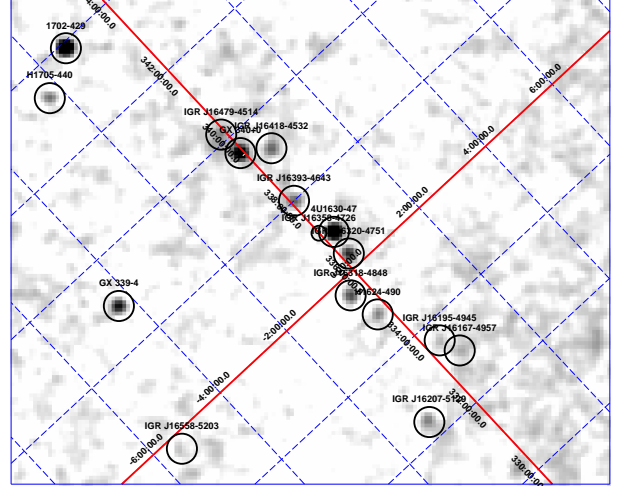


Figure 2. Close-up of the Norma Region. The image intensity scale and source markings are the same as for Figure 1, and this is also a 20–40 keV image.

3.2. 4U 1630–47

Figure 3b shows the *RXTE* All-Sky Monitor (ASM) 1.5–12 keV light curve for 4U 1630–47 for the current outburst (which is still in progress as of 2004 March). The peak flux of about 60 ASM is about 50% higher than the peak of the previous four outbursts occurring during the *RXTE* era. The 2003 February *INTEGRAL* observation (marked on Figure 3b) occurred during a time when the soft X-ray flux was decaying, but the hard X-ray flux was still relatively strong. Although strong, Figure 3a shows that the 20–40 keV flux declined during the observation. The nearly continuous ISGRI light curve indicates that the decline proceeded in a relatively gradual manner, and this figure also shows the 20–40 keV count rates for the PCA and HEXTE for the five *RXTE* pointings.

We extracted energy spectra for the ISGRI and SPI instruments on-board *INTEGRAL* and for the *RXTE* instruments PCA and HEXTE, and the fitted spectrum is shown in Figure 4. The spectrum is fitted with a model that has been used for previous outbursts (e.g., Tomsick & Kaaret, 2000) consisting of a disk-blackbody with $kT_{\text{in}} = 0.80 \pm 0.03$ keV plus a power-law with a photon index of $\Gamma = 2.09 \pm 0.03$. The model also includes interstellar absorption, a smeared iron edge, an iron emission line, and a high energy cutoff with a cutoff energy of 27 ± 4 keV and an exponential folding energy of 233 ± 40 keV. The PCA normalization is fixed to 1.0 and the other instrument normalizations are left free, giving 0.811 ± 0.005 for HEXTE, 0.60 ± 0.01 for ISGRI, and 1.36 ± 0.13 for SPI. Thus, the normalizations are not consistent between instruments. We have extracted power spectra using the PCA data. The power spectrum is well-described by a band-limited

Table 1. 4U 1630–47 and IGR Sources

Name	SNR	ISGRI Rate ^a	Identification or Comment	Reference
4U 1630–47	123.0	3.75	4U 1630–47	–
IGR J15479–4529	17.4	0.69	1RXS J154814.5–452845	Tomsick et al. (2004)
IGR J16167–4957	6.9	0.24	–	Walter et al. (2004)
IGR J16195–4945	5.8	0.20	AX J1619.4–4945, Bla star?	Walter et al. (2004)
IGR J16207–5129	11.5	0.42	A1Ive star?	Walter et al. (2004)
IGR J16316–4028	<4	<0.2	3EG 1631–4033 (?)	Rodriguez & Goldwurm (2003)
IGR J16318–4848	24.4	0.77	sgB[e] star ^b	Courvoisier et al. (2003)
IGR J16320–4751	32.7	1.01	AX J1631.9–4752	Tomsick et al. (2003)
IGR J16358–4726	<4	<0.2	K _s =12.6, P = 5850 s ^c	Revnivtsev et al. (2003)
IGR J16393–4643	16.8	0.54	AX J1639.0–4642 (3EG?)	Malizia et al. (2004)
IGR J16418–4532	16.8	0.54	–	Tomsick et al. (2004)
IGR J16479–4514	11.6	0.39	–	Molkov et al. (2003)
IGR J16558–5203	4.3	0.17	–	Walter et al. (2004)
IGR J17091–3624	<4	<0.3	1SAX J1709–36, radio	Kuulkers et al. (2003)
IGR J17195–4100	7.1	0.36	–	Walter et al. (2004)
IGR J17252–3616	10.8	0.82	–	Walter et al. (2004)

^a Here, we give the ISGRI count rate in the 20–40 keV band. The *RXTE* and *INTEGRAL* observations of 4U 1630–47 reported below can be used to obtain an approximate flux calibration. For 4U 1630–47, the 20–40 keV flux measured by *HEXTE* is 2.7×10^{-10} erg cm⁻² s⁻¹, and the ISGRI count rate is 3.75 c/s. Thus, 1.0 ISGRI c/s $\sim 7.2 \times 10^{-11}$ erg cm⁻² s⁻¹ (20–40 keV) ~ 6.5 mCrab.

^b See Chaty & Filliatre in these proceedings.

^c Pulsations reported in Patel et al. (2004).

noise component plus a power-law at low frequencies, and the 0.1–10 Hz fractional rms amplitude is 4%. The moderate level of timing noise and the strong power-law component in the energy spectrum indicate that the source was in an intermediate state between the canonical Soft and Hard states (See McClintock & Remillard, 2003, for a recent review of black hole spectral states.).

For the five *RXTE* observations, kT_{in} and Γ range from 0.74–0.82 keV and 2.11–2.18, respectively, but neither parameter correlates with the overall flux. Also, it is notable that the total disk-blackbody flux does not correlate with the total flux. The change in the total flux is driven by the change in the power-law normalization. The other quantity that is significantly different between observations is the high energy cutoff. A cutoff is only required at high significance for the second spectrum from the top, and the cutoff is not as sharp for the bottom two spectra. Often BHCs pass quickly through intermediate states, and these observations represent a useful study of the spectral evolution during intermediate states.

For much of the current 2002–2004 outburst, 4U 1630–47 has shown dramatic X-ray flaring behavior that is uncommon, although rapid, high amplitude flux changes have been reported for at least one previous outburst (Dieters et al., 2000). Figure 3c shows an example of this behavior from a 2003 May *RXTE* observation. Although not shown in this work, we made a hardness-intensity diagram for this light curve, indicating that there is a tight correlation between hardness and intensity.

4. SUMMARY AND CONCLUSIONS

- Fifteen of the 38 IGR sources are in the 4U 1630–47 field. Only three of the sources are not detected, indicating that as many as 12 of the sources are persistent. It is possible that a subset of the IGR sources are part of a new population of persistent, hard, intermediate luminosity X-ray sources.
- For much of its current outburst, 4U 1630–47 has shown dramatic flaring that is reminiscent of the flaring seen from GRS 1915+105. For 4U 1630–47, the hardness and intensity are correlated during the flares, indicating that these are hard flares that are related accretion (and possibly ejection) mechanisms rather than being due to, e.g., absorption from the outer edge of the disk.
- The ISGRI light curve (Figure 3a) and the spectra shown in Figure 5 show that 4U 1630–47 spectrum gradually changed, and the main change is in the normalization of the power-law component.
- The *RXTE* spectra indicate that the high energy cutoff also changes during the observations, and this sort of evolution must be kept in mind when combining *INTEGRAL* data from long observations.

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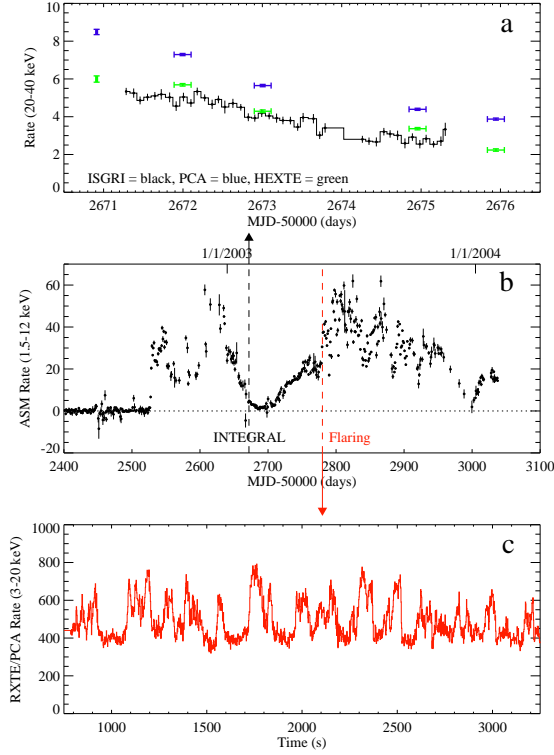


Figure 3. *4U 1630-47* X-ray light curves measured by (a) ISGRI, PCA, and HEXTE, (b) the RXTE ASM, and (c) the PCA. The ASM light curve for the current outburst is shown in (b). 20-40 keV light curves are shown in (a). An example of the *4U 1630-47* X-ray flares is shown in (c).

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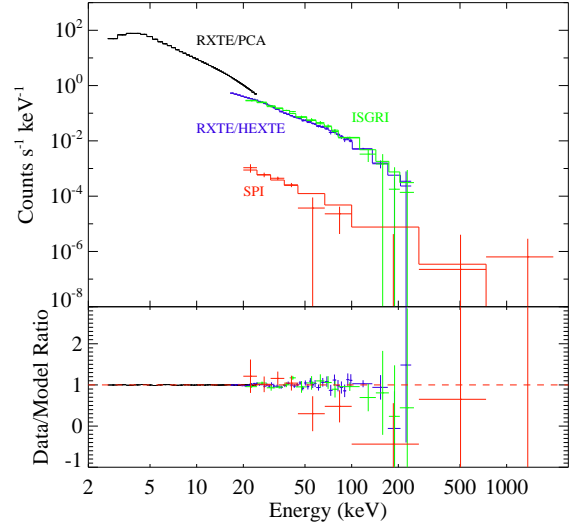


Figure 4. The *INTEGRAL* and *RXTE* 3-2000 keV energy spectrum. The exposure time for *INTEGRAL* is 293 ks, while the exposure time from the PCA is 43 ks, and the exposure time for HEXTE is 28 ks.

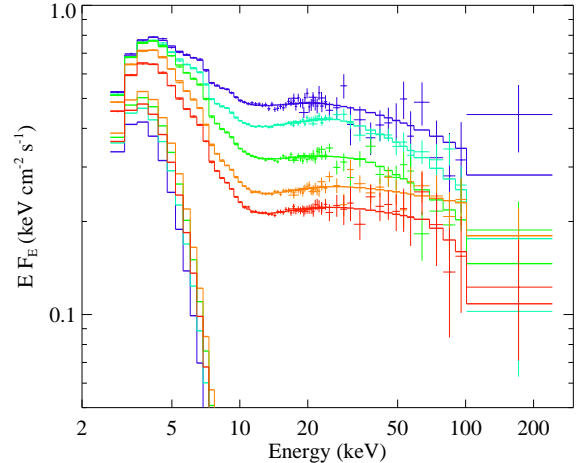


Figure 5. *RXTE* PCA and HEXTE energy spectra for the five observations made during or close to the time of the *INTEGRAL* observation. Figure 3a shows that the flux was gradually falling, and the spectra are in chronological order from top to bottom.